HYDROMETEOROLOGICAL DISASTERS IN THE BAGHMATI-ADHWARA RIVER BASIN, BIHAR

A

SYNOPSIS

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I. Introduction

Hydrometeorological disasters that comprises of catastrophic forces of floods and droughts, act as agent of change that shapes both natural and human landscapes. These hazards pose great risk because of complex interrelationship between atmospheric and hydrological processes, that are often accentuated by long term climatic variability and anthropogenic activities. Floods, characterized by surplus overflow of water running and often crossing natural barriers onto dry land, and droughts, marked by long periods of dry spell resulting in water scarcity, represent two ends of the hydrological disasters, each imposing severe threats and affecting natural ecosystems and human societies.

Floods are regarded as most devastating hazard with maximum potential to cause damage in terms of area inundation, landscape modification leaving large number of people stranded. Few processes such as deforestation, land use transformation, rapid urbanization, destabilization of slope have been known to intensify impact of floods, often calling for need of state intervention for comprehensive disaster management and mitigation strategies. On the contrary, droughts, characterised by extended water deficits, affects spoil moisture, net primary productivity, burden existing eater reserves and challenge socio-economic hardships. As the duration, intensity and frequency of these hydrometeorological events continue to increase, a deep understanding of the underlying processes, causative factors, and climate forcings becomes imperative for building resilient communities and in devising sustainable development strategies for water resources.

Floods in Bihar is an annual feature that are often led by heavy monsoonal rainfall, causing perennial rivers such as Ganga, Gandak, Baghmati, Kamla, and Kosi to overflow to banks and cause damage to infrastructure, transportation network, agriculture and displacement of large population. The north Bihar topography is fabricated with network of streams that brings flood with fresh silt from hills in north and deposits these in plains area. But this flooding events are frequently interrupted by frequent episodes of droughts which with their long-term dry spells challenge agriculture economy and threaten water supply systems.

The presence of the Himalayan foothills in the north and the Gangetic plains to the south makes North Bihar vulnerable to climate extremes with hydrometeorological disruptions impacting

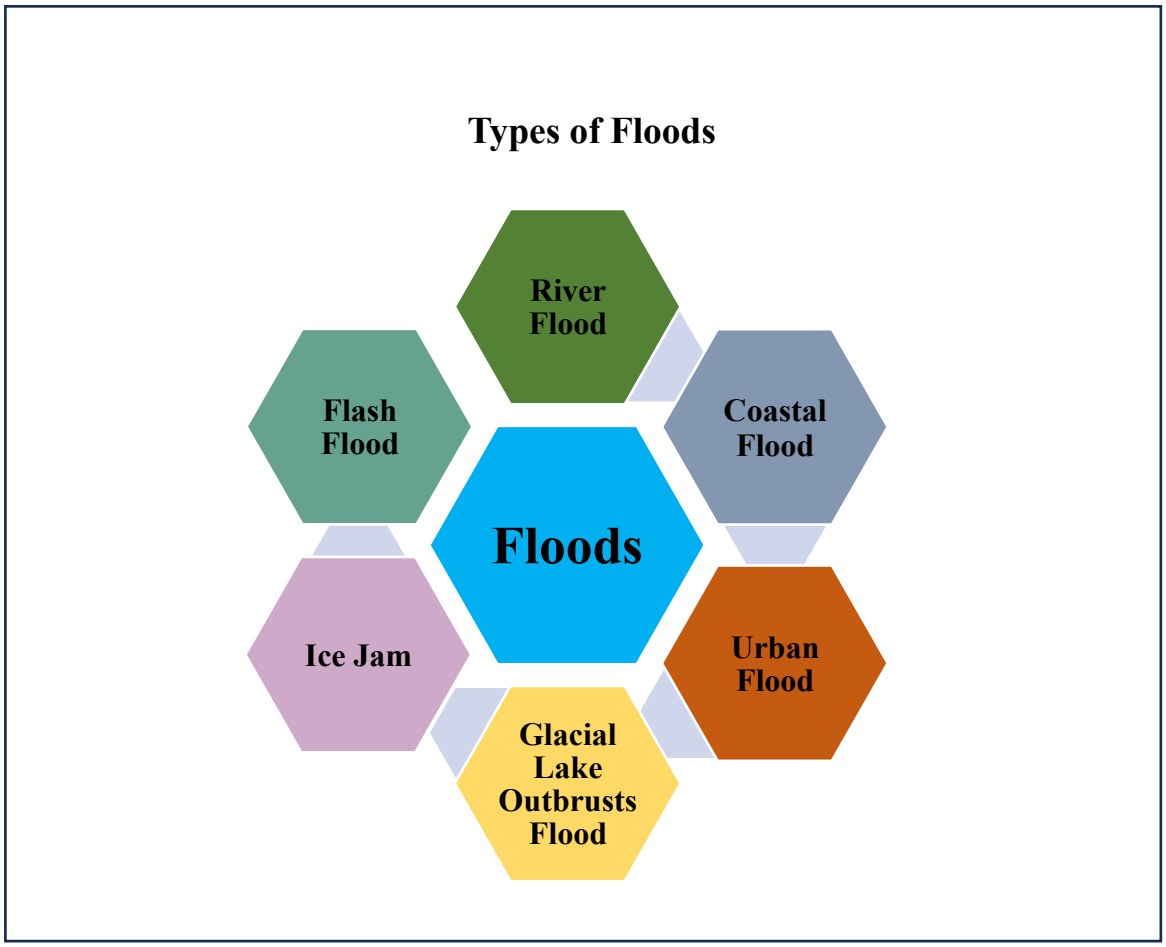
lives and livelihoods of its dwellers. Situated in the heartland of Bihar, the Bagmati-Adhwara River basin is a critical geographical region that is hydrologically dynamic and faces dual challenges of hydrometeorological disasters—specifically, floods and droughts. This doab region carved by Baghmati-Adhwara group of rivers not only thrives the agro based economy of this region but also makes the communities residing in its catchment area vulnerable to the forces of nature. This dual action of cyclic floods and droughts along with impact of climatic extremes makes this basin an important focal point for understanding unravelling specific vulnerabilities and building context-specific resilience of communities.

II. Conceptual Framework

Hydrometeorological Disasters: These are natural processes or phenomena of atmospheric, hydrological or oceanographic nature, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (United Nations International Strategy for Disaster Reduction, UNISDR). It includes floods, debris and mud floods, tropical cyclones, storm surges, thunder or hailstorms, rain and wind storms, blizzards and other severe storms, drought, desertification, wild land fires, temperature extremes, sand or dust storms, permafrost and snow or ice avalanches.

1. Floods

According to NIDM (National Institute of Disaster Management), **"***A flood is an excess of water (or mud) on land that's normally dry and is a situation wherein the inundation is caused by high flow, or overflow of water in an established watercourse, such as a river, stream, or drainage ditch; or ponding of water at or near the point where the rain fell. This is a duration type event. A flood can strike anywhere without warning, occurs when a large volume of rain falls within a short time.* According to WHO (World Health Organization), "*Floods are the most frequent type of natural disaster and occur when an overflow of water submerges land that is usually dry*". While NDMA (National Disaster Management Authority) defines as, "*Floods are a recurrent phenomenon, which cause huge loss of lives and damage to livelihood system, property, infrastructure and public utilities."* According to the International Federation of Red Cross and Red Crescent Societies (IFRC)*, "Floods are when water overflows from the normal boundaries of a stream, river or other body of water, or accumulates in an area that is usually dry*".



(a) **Flash Floods:** Floods occurring within six hours, mainly due to heavy rainfall associated with towering cumulus clouds, thunderstorms, tropical cyclones or during passage of cold weather fronts, or by dam failure or other river obstruction. This type of flood requires a rapid localized warning system.

(b) **River Floods:** Floods caused by precipitation over a large catchment's area, melting of snow or both. Built up slowly or on a regular basis, these floods may continue for days or weeks. The major factors of these floods are moisture, vegetation cover, depth of snow, size of the catchment's basin, etc.

(c) **Coastal Floods:** - Floods associated with cyclonic activities like Hurricanes, Tropical cyclones, etc. generating a catastrophic flood from rainwater which often aggravate wind-induced storm and water surges along the coast.

(d) **Urban Floods:** As land is converted from agricultural fields or woodlands to roads and parking lots, it loses its ability to absorb rainfall. Urbanization decreases the ability to absorb water 2 to 6 times over what would occur on natural terrain. During periods of

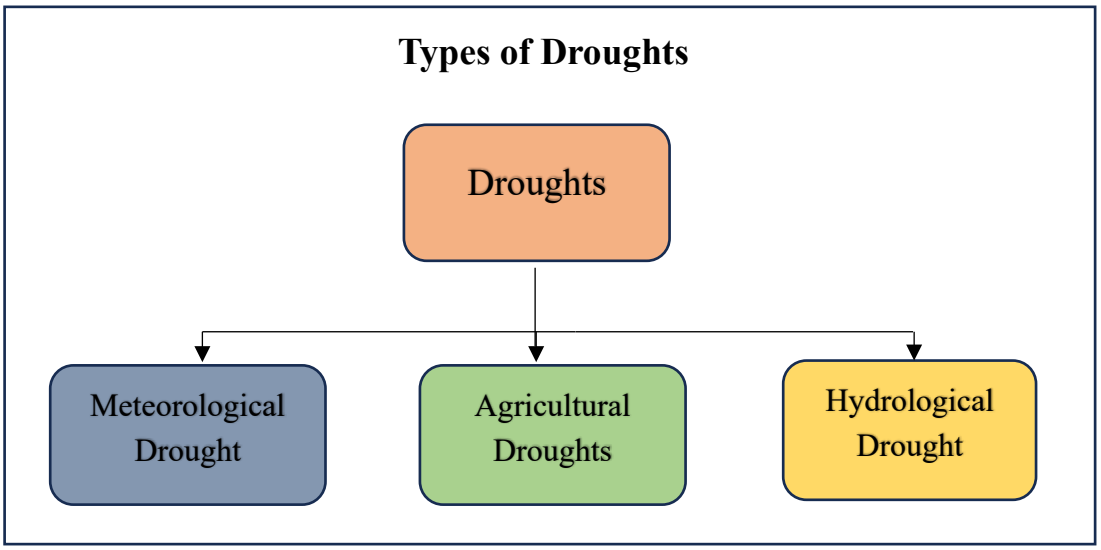
urban flooding, streets can become swift moving rivers, while basements can become death traps as they fill with water.

(e) **Ice Jam:** Floating ice can accumulate at a natural or human-made obstruction and stop the flow of water thereby causing floods. Flooding too can occur when there the snow melts at a very faster rate.

(f) **Glacial Lake Outbursts Flood (GLOF):** Many of the big glaciers which have melted rapidly and gave birth to the origin of a large number of glacier lakes. Due to the faster rate of ice and snow melting, possibly caused by the global warming, the accumulation of water in these lakes has been increasing rapidly and resulting sudden discharge of large volumes of water and debris and causing flooding in the downstream.

2. Drought

Drought refers to an extended period of low precipitation within the natural climate cycle, capable of manifesting globally. This gradual-onset calamity is distinguished by insufficient rainfall, leading to a deficit in water supply. Drought is a duration marked by conditions drier than usual, leading to issues related to water. Reduced rainfall over several weeks, months, or years causes diminished stream and river flows, lower water levels in lakes and reservoirs, and an increase in well water depths. If dry conditions persist, giving rise to water-supply challenges, the period of aridity transforms into a drought. The interpretation of the term "drought" varies among individuals, influenced by how the scarcity of water impacts them.
According to NIDM, 'Drought is a normal, recurrent feature of climate and occurs in all climatic regimes and is usually characterized in terms of its spatial extension, intensity and duration. Conditions of drought appear when the rainfall is deficient in relation to the statistical multi-year average for a region, over an extended period of a season or year, or even more'.



a. **Meteorological Drought** - It is defined as the deficiency of precipitation from expected or normal levels over an extended period of time. Meteorological drought usually precedes other kinds of drought. Meteorological drought is said to occur when the seasonal rainfall received over an area is less than 25% of its long-term average value. It is further classified as moderate drought if the rainfall deficit is 26–50% and severe drought when the deficit exceeds 50% of the normal.
b. **Hydrological Drought** - It is best defined as deficiencies in surface and subsurface water supplies leading to a lack of water for normal and specific needs. Such conditions arise, even in times of average (or above average) precipitation when increased usage of water diminishes the reserves.
c. **Agricultural Drought** – It is usually triggered by meteorological and hydrological droughts, occurs when soil moisture and rainfall are inadequate during the crop growing season causing extreme crop stress and wilting. In India, it is defined as a period of four consecutive weeks (of severe meteorological drought) with a rainfall deficiency of more than 50% of the long-term average (LTA) or with a weekly rainfall of 5 cm or less from mid-May to mid-October (the kharif season) when 80% of India's total crop is planted or six such consecutive weeks during the rest of the year (NRSC, Decision Support Centre).

III. Review of Literature

Impact of hydrometeorological disasters is so deep and diverse in nature that a detailed review of literature is needed to understand

(a) underlying processes,

(b) to learn latest advancements in this field,

(c) to identify research gaps, and

(d) to contribute towards effective mitigation, building strategies and predict future implications for the highly variable nature of hydrometeorological disasters in river basins.

For the present study the review of literature has been done according to following subthemes:

1. Hydrometeorological Disasters in Himalayan foreland river basin.

In the genre of studies on hydrometeorological disasters, river basins emerge as dynamic systems where interaction of climatological, geological and hydrological processes gives birth to catastrophic events. As global communities cope with increasing frequency and intensity of floods, droughts, and other hydrometeorological phenomena, a wide-ranging knowledge of available scientific literature becomes important. that converge to shape the landscape and dictate the nature of disasters. This section of review engages literature dedicated to hydrometeorological disasters within river basins, with an aim to understand the interplay of climatic variables, hydrological processes which impact on aquatic, terrestrial ecosystem coupled with human ecosystems.

Several studies have been carried out to investigate the extent and impact of droughts in various part of the world using various methodologies in which Standardized precipitation index method in a GIS environment is used to map the spatial extents of drought hazards in different time steps- short, intermediate as well as for long time scales (Sarker et al. 2020; Pandey et al. 2019; Shahid and Behrawan 2008). Numerous study has been carried out on flood susceptibility zonation in Himalayan Foreland Basin using advanced ensemble machine learning model such as random forest (RF), support vector machine (SVM) and extreme gradient boosting (XGBoost)) (Ghosh, Saha, and Bera 2022;Talukdar et al. 2020). While many scientific studies have been carried out to explore drought in Himalayan countries using MannKendall test for trend analysis, SPI and SPEI for drought assessment, and Pearson Correlation Coefficient and Simple Linear Regression for evaluating SPI and SPEI relationships and ANN, SVM, and RF for prediction.(Akter et al. 2023; Chandrasekara et al. 2021;Hoque, Pradhan, and Ahmed 2020; Khan et al. 2020).

Several studies also delved into the idea that changes in the land utilization pattern is affected by recurrent flood events.(Raha, Gupta, and Biswas 2023; Janizadeh et al. 2021; Onyeizugbe and Onyejiaka 2019; Bronstert, Niehoff, and Brger 2002) Other important themes such as morphometric analysis of river basins in Himalayan foreland, for a understanding of the causal factors of spatial inhomogeneities in basins, and morphometric characterization of their hinterlands also engaged attention of researchers. (Swarnkar, Sinha, and Tripathi 2020; Agarwal, Parkash, Ali et al. 2012). Important drainage network parameters, such as bifurcation ratio (Rb), drainage density (Dd), stream frequency (Sf), texture ratio (Rt) drainage intensity (Di) significantly contribute to the hydrological response of a watershed. Bifurcation ratio (Rb)

is an important control over the ‘peakedness’ of the run-off hydrograph (Karmokar and De 2020). The frequency and intensity of Hydro-meteorological disaster (HMD) is increasing in Himalayan states as in the last few years. This region has experienced large number of hydrometeorological disasters such as high-intensity precipitation, cloud burst and subsequent flash flooding in downstream areas, snow avalanches, glacier lake outburst floods (GLOF), hail storms, drought and rainfall-induced mudflows and reveals that fluctuating rainfall regime produces a unique spectrum of extreme events (Pandey and Mishra 2021; Thakur et al. 2018; Thakur, S., & Chandel 2016)

2. **Studies on Floods and Droughts in river basin**.

The frequency of alternating cycles of floods and droughts within river basins demands a deep exploration of scientific literature to understand how influence of climate change continue to affect hydrological cycles in river basins. It also helps to understand evolving patterns and trend of consequences of climate extremes. This review also attempts to explore extensive literature of government policy documents and other research findings to evaluate ongoing discourse on effective flood and drought management within river basins.

Many scholars have analysed the droughts and floods by using indices standard precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) (Ünal 2023; Alkan and Tombul 2022; Wei et al. 2021; Alsafadi et al. 2020; Fan et al. 2019). cIn China a study on Yellow River Basin (Bai et al. 2016) reveals that anthropogenic impacts play an increasingly important role in the annual maximum flood (AMAXF) changes in river basin In this study Mann-Kendall test and Trend Index method were used . Hossain (2023) reported that the real time forecasting map, flood hazard map, and flood shelter suitability map are very helpful to reduce the damage of the flood affected area. It utilised Artificial Neural Network (ANN) model and NOAA AVHRR image for the study. Elsafi, 2014 conducted a study on Nile River in Dangola station, Sudan to validate the accuracy of Artificial Neural model (ANN) and indicates that ANN models are viable for forecasting of Floods. Many research on flood estimation have been conducted using various methodologies in various parts of the world among them most common used methods were ‘HEC-RAS’ model and ‘Analytic Hierarchy process’ (AHP) method (Khattak et al. 2016; Ouma and Tateishi 2014; Reza Ghanbarpour et al.2011;S.M.J.S.Samarasinghea,H.K.Nandalalb,D.P.Weliwitiyac,J.S.M.Fowzed, M.K.Hazarikad 2010).

Kumar et al.2023, reported that high degree of vulnerability to flood risk in the river basins of the Ganga, Brahmaputra, and Godavari, while some regions within the northern Indus basin, Luni basin, and western areas on the leeward side of the Western Ghats had lower Flood susceptibility by using Multicriteria Decision Making (MCDM) Model and AUROC assessment tool. Roy and Bhusan, 2017 stated that the flood damage continues to show an increasing trend despite the introduction of substantial structural and non-structural flood control measures during past several decades in the country (India). Sarkar (2022) studied trend of floods and droughts in Godavari River basin using Standardized Precipitation Evapotranspiration Index (SPEI), Mann Kendall's test and Sen's slope.

Sneha (2020) conducted a study on Implication of Data Assimilation on Real Time Flood Forecasting in Baghmati river basin and stated that data assimilation is very useful specially when there is a sudden change in the real time or forecasted rainfall. Subedi, Poudel, and Acharya (2019) conducted a study on shifting of Baghmati River using Normalized Difference Water Index (NDWI) for the unsupervised extraction of the water feature and monitoring the changes and reported a major temporal shift in the river channel with a decreasing trend from 1991 to 2016. It found that over 25 years, the river lost almost one-third of its original water-flow channel. Rastogi et al. (2018) has carried out study on Baghmati River Basin and used Digital Elevation Model (DEM) from shuttle radar topography mission (SRTM) to create detailed sub-basin and river network map of entire Bagmati basin. Tripathi (2022) reported that total ~34% of the geographical area of North Bihar was inundated in the last 20 years and the maximum flood extent was seen in 2020. Flood risk map exhibited that ~7%, ~8%, ~13%, ~4%, and ~2% of the geographical area was mapped under Very High, High, Moderate, Low, and Very Low categories, respectively. (Manjan 2020) has carried out a study on hydrological modelling of Baghmati River Basin using SWAT model. While few studies also elaborated the adverse impact of embankment built on Baghmati River where it has enhanced the vulnerability of floods in this basin. (Kumar 2021; Mishra 2008)

3. Impact of Climate Change on hydrometeorological disasters.

Climate change is a global concern today where its impact on hydrometeorological disasters and increasing intensity and frequency of extreme weather events has emerged as a critical area of study. This section of review explores available literature to identify relationship between variables of climate change and hydrometeorological disasters. With a special on focus on floods and droughts, this examination seeks to unravel the complex interplay of

atmospheric and hydrological processes. Climate change increases the hazard of hydrometeorological disasters such as floods and drought which influences harvest area an agricultural commodity (Fitriana L, Susanto S, Ngadish, Setyawan C 2021). Several studies have been carried out to assess the potential impacts of climate change on hydrometeorological variables and drought characteristics using the Soil and Water Assessment Tool (SWAT) model to assess changes in watershed hydrology. Mann–Kendall Test for trend analysis in hydrological and climatological time series data, and Standardized Precipitation Index (SPI), Streamflow Drought Index (SDI), and Reconnaissance Drought Index (RDI) to identify the characteristics of meteorological, hydrological, and agricultural droughts have also been used extensively.(Orke and Li 2022; Sahu et al. 2020). Kelman (2015) studied on climate change within the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), and analyzed how climate change is mentioned in the framework's text and the potential implications for dealing with climate change within the context of disaster risk reduction. Urama and Ozor (2010) and Kundzewicz et al. (2014) reported that climate change is having a multitude of immediate and long-term impacts on water resources and flood characteristics. (Wu et al. 2021) assessed impacts of Climate Change on Discharges and Extreme Flood Events in the Upper Yangtze River Basin in China and reported that decreases in precipitation may always result in the decrease in mean discharge, but increases in precipitation did not always lead to increases in discharge due to high temperature rise. Climatic extreme events were projected to become more intense and frequent in the future, which could have potential devastating impacts on the society and ecosystem in this region.

(Rawat K. Praddep, Tiwari C. P.,and Pant C Charu 2011) reported that climate change is accelerating hydrological hazards and risks in Himalayan region such as high runoff, flash flood, riverine flood, soil erosion and denudation during monsoon season and drought during non-monsoon period as dry up of natural springs and decreasing trends of stream discharge etc.

Umar et al. (2022); Zakwan et al. (2022); and Srivastava et al. (2021) conducted studies to analyze the trend of Hydro-meteorological parameters using Mann-Kendall (M-K), Sen's slope, and innovative trend analysis (ITA). Climate change impacts will not only result in severe disasters of floods and drought, but will also reduce the carrying capacity as well as assimilative capacity of the river by affecting its abiotic and biotic components.(Bhunya et al. 2021;Jain and Singh 2020). Ganges-Brahmaputra-Meghna (GBM) delta is one of the most vulnerable deltas of world in context of climate change. The remarkable change in GBM basin

climate is likely to have a significant impact on its rivers, which could enhance the flooding potential and drought problem.(Singh and Balwant 2014). Das et al. (2021); Naga Sowjanya et al. (2022) conducted a study to analyse the effects of climate change on hydro-climatological components in river basins using SWAT hydrological model and to assess the future climate change effects on hydrological variables, MIROC-ESM, MIROC-ESM-CHEM, MIROC_MIROC5, and MOHC_HADGEM2_ES Global Climate Models (GCMs) under RCP 4.5 and RCP 8.5 were applied in the calibrated SWAT model.

Srivastava et al. (2003) and Islam et al. reported that the changes of rainfall quantities and frequencies directly changing the stream flow pattern and its demand, spatiotemporal allocation of run-off, ground water reserves and soil moisture. Changes in hydrometeorological patterns worldwide have been influenced by the rise in global greenhouse gas emissions over the last century. This changed rainfall amounts and patterns, causing occasional droughts and floods. (Sharma and Priya 2023). Kumar and Medalist (2019) conducted a study to detect the hydroclimatological changes in the Bagmati River Basin, Nepal. It reported an increasing trend of temperature in all seasons, although the change rate was different in different seasons for both minimum and maximum temperatures. However, stronger warming trend was found in maximum temperature in comparison to the minimum in the whole basin. Both precipitation and discharge trend were increasing in the pre-monsoon season, but decreasing in the postmonsoon season.

4. Future Implications of Floods and Droughts.

The prospective implications of floods and droughts will help to understand the direction and magnitude in which these hazards will shape hydrometeorological landscapes, ecosystems, and human societies. It will provide a comprehensive possible outcome that will guide in devising resilient strategies, frame adaptive measures, build resilience and develop global cooperation to mitigate impacts of climate change. In the future, as CO2 continues to rise, we can expect more extreme events like floods, droughts, fires, and melting ice caps. This has profound implications for the way we manage and organize our societies. Before we can manage something, we have to make sense of the situation.(Whiteman 2011). Jose and Cruz (1999); Manatsa, Chingombe, and Matarira (2008) used global circulation models (GCMs) to assess the potential future climatic changes on the Nzoia catchment in the Lake Victoria basin and in the Angat reservoir and Lake Lanao, and reported that, runoff is likely to decrease in the future and be insufficient to meet future demands for water. Mukherjee and Mishra (2021) and Mukherjee et al. (2018) reported that India has witnessed some of the most devastating extreme

precipitation events, triggered by atmospheric rivers (ARs), leading to massive flooding. Trenberth (2005) stated that there is a direct influence of global warming on changes in precipitation and heavy rains. Global warming has a direct influence on changes in precipitation and the hydrological cycle (Sharma 2019). While precipitation amount is most commonly considered, even bigger changes occur in its intensity, frequency and type Trenberth (2009). The recent Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) showed that in the near term, every region in the world is projected to face further increases in climate hazards and the Indian Ocean is experiencing the world's fastest rate of ocean surface warming.

IV. Research Gaps

From the above review of literature, we can conclude that:

(a) River basins are dynamic systems where climatological, geological, and hydrological processes interact to cause catastrophic events. Increasing frequency and intensity of floods, droughts, and hydrometeorological phenomena globally necessitate a comprehensive understanding of scientific literature.

(b) Various studies have been conducted on Floods and Droughts events in River Basins across India employing methodologies like Standardized Precipitation Index (SPI) and advanced ensemble machine learning to analyse drought extent and impact. Flood susceptibility zonation in Himalayan Foreland Basin has also been investigated using machine learning models. Changes in land utilization patterns also lead to recurrent flood events in river basins. This invokes an idea for a detailed scientific investigation of floods and droughts occurrences and their relationship with land use in a microcosm like Baghmati-Adhara basin using modern tools and techniques.

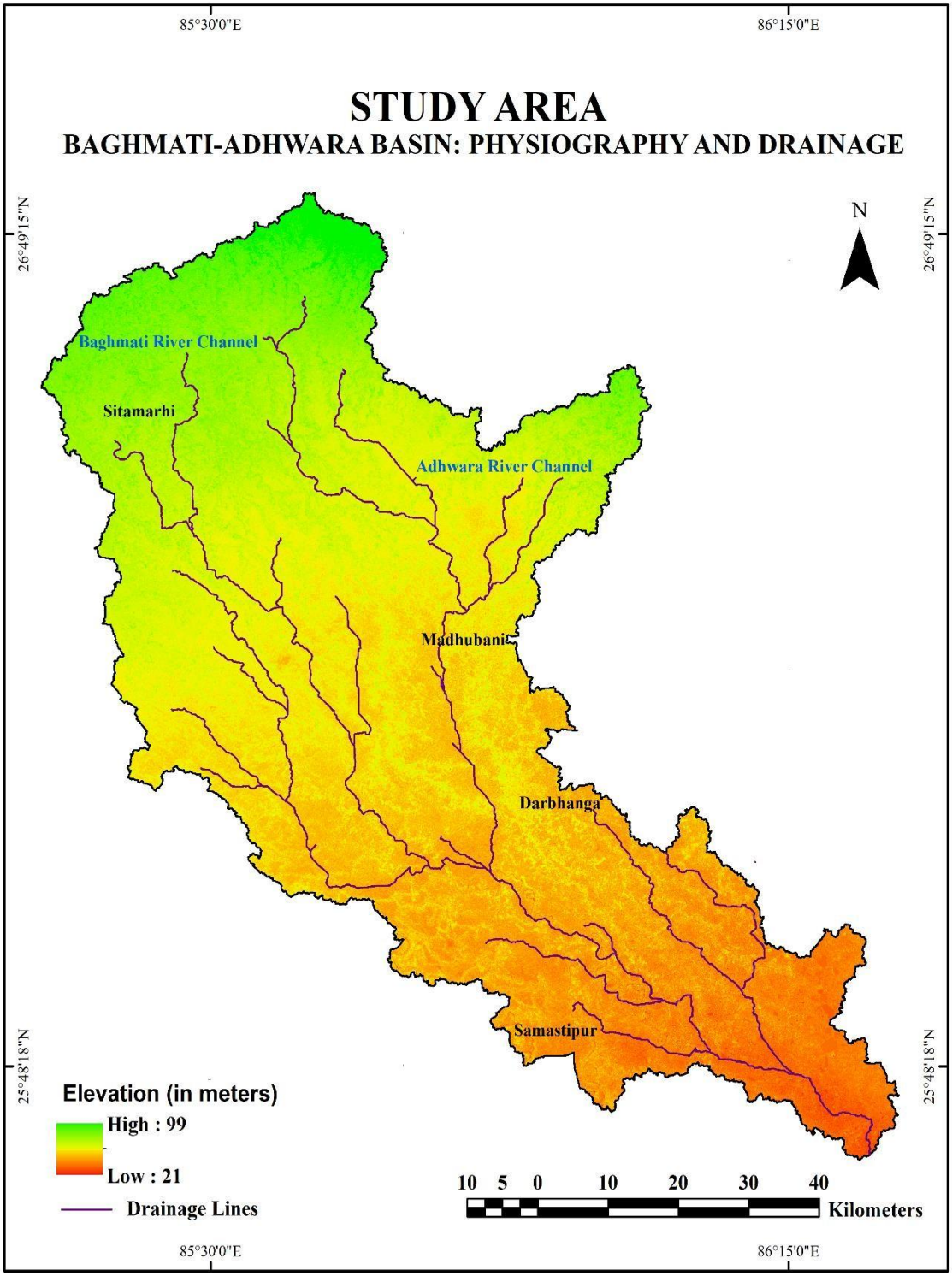
(c) Various studies use models like SWAT, Mann-Kendall Test, SPI, SDI, and RDI to assess climate change impacts on hydrometeorological variables and drought characteristics. Climate change is found to accelerate hydrological hazards and risks in the Himalayan region, affecting runoff, flash floods, riverine flood, soil erosion, and drought. Hence, a detailed study on impact of climate change on micro-regions like Baghmati-Adhwara basin is needed to explore hydrological hazards and associated risks in this region.

(d) Prospective implications of floods and droughts are crucial for understanding their potential impacts on landscapes, ecosystems, and human societies. Global cooperation, resilient strategies, and adaptive measures are needed to mitigate the impacts of climate change on hydrometeorological disasters. This warrants a systematic study on possible future implications of hydrometeorological disasters in a backward state like Bihar.

V. Study Area

The Baghmati River basin is located in the Himalayan foreland basin, falling under state Bihar (India) and Nepal. The Baghmati River originates from Shivpuri range in Nepal, and forms a basin area of approximately 8848 km2. Its total length is 589 km out of which,
394 km lies in Bihar and rest 195 km lies in Nepal. Lakhandei, Darbhanga Baghmati and Old Kamla forms its left bank tributary while Lal Bakiya, Hasanpur Baghmati forms right bank tributaries. Budhi Gandak Basin lies in west, while in the east side Adhwara basin emerges from Nepal Himalayas in the north. In the south of Himalayan front in upper reaches, the river displays a braided pattern. It flows over the Indian soil in the district of Sitamarhi, Sheohar, East Champaran, Muzaffarpur, Darbhanga, Samastipur, Khagaria and Begusarai. After travelling downstream through these districts and before confluence with the river Kosi, it is characterised by a single-channel meandering river system. This foreland basin is tectonically active with differential rates of upliftment. The river exhibits 'hyper-avulsive behaviour' with sudden abandonment of existing channel for a new course and 'anabranching' where it separates from main channel and flows parallel to main channel. It also exhibits exhibit anastomosing characteristics where two or more interconnected channels are separated by floodplain segments. Several alterations in the river course have been observed that has led to various short-term abandoning of channels. Most abandoned channels are partially filled by monsoonal precipitation.

Average annual rainfall in the basin is about 1255 mm. The Baghmati River basin experiences nearly uniform rainfall from SW Monsoon, contributing to the high sediment load and frequent overbank flooding in the region. The morphology of channel narrows down from being shallow at Dhengbridge to becoming deep at Hayaghat. The Baghmati plains frequently face overbank flooding due to high annual and decadal rainfall variability and periodic elevated discharge. During monsoon it carries heavy sediment load and experiences overbank flooding thus, resulting in breaches and channel avulsion. As a result, it displays several fluvial anomalies such as compressed meanders, knick points, channel incision, and changes in river flow direction. The area is also influenced by active subsurface faults, where geography of the Baghmati River basin is shaped by tectonic activity, high sediment load, and dynamic fluvial processes.



Source: SRTM DEM 2014

VI. Objectives

1. To provide a morphometric analysis of Baghmati River basin.
2. To identify spatial patterns and trends of flood inundation and drought affected areas in the Baghmati River Basin.
3. To investigate the influence of precipitation variability on the frequency, intensity, and duration of floods and droughts in Baghmati River basin.
4. To analyse future implications and modelling of floods and droughts in Baghmati River basin.

VII. Research Questions

1. What are the key morphometric characteristics of the Baghmati River basin?
2. Are there any identifiable trends in the frequency and severity of flood and drought events in different regions of the Baghmati River basin?
3. What are the specific precipitation thresholds that trigger floods and droughts in the Baghmati River basin?
4. What are the implications of future climatic scenarios on the vulnerability and resilience of the Baghmati River basin to extreme hydrological events?

VIII. Data Sources and Methodology

In this study, following data sources and methodology (Table1,2 and 3) will be employed for understanding and analyzing the hydrological patterns, flood susceptibility, and drought intensity in Baghmati-Adhwara River basin. The study will incorporate both primary and secondary data, with primary data collection relying on Stratified Sampling Method, Questionnaire, Observation, and Interview Methods. To ensure the robustness of the study, data will be procured from meteorological organizations viz. Indian Institute of Tropical Meteorology (IITM) and the Indian Meteorological Department (IMD) for rainfall and temperature data spanning from 1901 to 2023. Flood inundation data, acquired from satellite imagery like Landsat-8, IRS LISS-IV, MODIS, and SRTM, will be used in association with annual reports published by Central Water Commission (CWC), Patna. Open series toposheets will be accessed from the Survey of India, while aerial photographs will be obtained from Planetscope, National Remote Sensing Centre (Hyderabad), and the Indian Institute of Remote

Sensing (Deharadun) and Bhoonidhi webportal. Historical flood and drought-related data will be extracted from published reports from various reputable organizations. The study extensively utilizes satellite data with different sensors and spatial resolutions, including IRS, RESOURCESAT, CARTOSAT, RADARSAT, RISAT, SENTINEL, Terra SAR-X, and ALOS-2, for annual flood inundation and flood hazard mapping.

To assess flood susceptibility zones and drought intensity, the study incorporates a set of parameters. Statistical methods such as Modified Mann Kendall test and Sen slope estimator will be employed, alongside indices like Precipitation Concentration Index (PCI), Standard Precipitation Index (SPI) and Rainfall Anomaly Index (RAI). Additionally, the study includes calculation of Sinuosity Index, calculated as the length of the stream channel divided by the length of the straight-line distance. For hydraulic modeling, flood risk analysis, and flow analysis, the study relies on the HEC-RAS Model and MIKE Model. This methodological framework ensures a comprehensive and rigorous approach to understanding hydrological dynamics and related risks in the study area. As maps will be the basic tool for the research work, the ArcGIS Pro software will be used to plot the spatial dimension in the region. The mapping of different flood and drought scenarios shall be done by interpolating data using Spline, an algorithm shall be applied for spatial interpolation. Tables, charts, graphs and diagrams shall be prepared for statistical representation of data. On the basis of trends and patterns of floods and droughts, implications of these hydrometeorological disasters scenario shall be visualized.

DATA COLLECTION
IMD /IITM
Rainfall
Temperature
GSI
SATELLITE IMAGES
DEM
SOI TOPOGRAPHIC SHEETS
HISTORICAL RECORDS: PUBLISHED REPORTS
SPI
RAI
PCI
Rainfall Extremes
Geomorphology
Geology
LULC
Elevation
Slope
TWI
Soil Texture
Curvature
Flow Accumulation
Catchment Area
Drainage Pattern
Stream Order
Attribute Data (LOSS & DEATH)
Climatological Analysis
Hydrological Analysis
Statistical Analysis
GIS: FLOOD MAPPING
RISK ASSESSMENT
FLOOD MODELLING
FUTURE IMPLICATION & MITIGATION
ANALYSIS REPORT AND POLICY DOCUMENTATION

IX. Tentative Chapter Scheme

The present study will be organized in the following chapters:

Chapter I. Conceptual Framework

Chapter II. Hydrometeorological Disasters in Baghmati-Adhwara River basin

Chapter III. Floods and Droughts in Baghmati-Adhwara River basin

Chapter IV. Assessment of Rainfall Variability on Floods and Droughts

Chapter V. Future Implications of Hydrometeorological Disasters

Chapter VI. Summary and Conclusions

TIME SCHEDULE

The tentative time schedule for the purpose research is given below:

S.no	Activity	Time Required
1	Updating review of literature	Till completion of thesis
2	Data collection and processing	Fourteen months
3	Data analysis	Ten months
4	Report writing	Twelve months
5	Total time	Thirty-Six months

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